POWER FACTOR CORRECTION CIRCUIT

Field of the Invention

The present invention relates to a power factor correction circuit and more particularly, to a power factor correction circuit for improving a power factor of a switching power supply designed in flyback topologies in order to comply with the requirements of Class A or Class D as stipulated in the harmonic current rules EN-6100-3-2.

Background of the Invention

A typical switching power supply is shown in Figure 1. The supply comprises an AC/DC rectifier 1 and a DC/DC converter 2 in which an electrolytic capacitor C_3 is connected as a filter for the bridge rectifier BD_1.

Figure 5 discloses a circuit structure in which the DC\DC converter 2 shown in Figure 1 is a half-bridge converter. In accordance with the design structure shown in Figure 5, a bridge rectifier BD_1 is used to rectify the AC power V_{S1}. A capacitor C_3 is then used to filter the rectified power and generates a DC voltage V_{C3}. The capacitor C_1 and the capacitor C_2 are connected to a common node to form a voltage divider. Therefore, the voltage at the common node between the two capacitors is $V_{C3}/2$.

Figure 6 is a time chart for the PWM signals, V_{HG} and V_{LG}, which are driving signals for the switches Q_1 and Q_2 shown in Figure 5, respectively.

Both PWM signals V_{HG} and V_{LG} are low (low voltage) for $0 \leqq t \leqq t_1$, at which time the switches Q_1 and Q_2 are both turned off. Therefore, the output voltage V_O is supplied by the capacitor C_4.

When $t_1 \leqq t \leqq t_2$, the PWM signal V_{LG} is high (high voltage) and the PWM signal V_{HG} is low (low voltage), at which time the switch Q_1 is turned off and the switch Q_2 is turned on. The current then flows through the capacitor C_1, the primary winding P_1 and the switch Q_2 to the ground. In this situation, the transformer transfers the power from the primary winding P_1 to the secondary winding S_1 to supply power to the capacitor C_4 and output a voltage V_O.

When $t_2 \leqq t \leqq t_3$, the switches Q_1 and Q_2 are once again both turned off, making the operation state of the circuit the same as that when $0 \leqq t \leqq t_1$.

When $t_3 \leqq t \leqq t_4$, the PWM signal V_{LG} is low (low voltage) and the PWM signal V_{HG} is high (high voltage), at which time the switch Q_1 is turned on and the switch Q_2 is turned off. The current then flows through the switch Q_1, the primary winding P_1 and the capacitor C_2 to the ground. The transformer transfers the power from the primary winding P_1 to the secondary winding S_2 to supply power to the capacitor C_4 and output a voltage V_O.

The power switching cycle described above is performed repeatedly to supply power to a load while the output voltage V_O is transferred to a feedback system 12. The feedback system 12 feeds a signal back to the high-frequency pulse signal control circuit 50 to modify the duty cycle of the PWM signals V_{HG} and V_{LG}. For example, if the power supplied to the load is insufficient when the output voltage is lower than a required value, the feedback signal lengthens the duty cycle of the PWM signals V_{HG} and V_{LG} to increase the conduction

time of the switches Q_1 and Q_2. In effect, power is transferred from the primary winding to the secondary winding of the transformer T_1 for a longer period of time; that is, the power supplied to the secondary winding is increased. The output voltage V_O consequently increases to attain the required voltage. This means, however, that the power supplied to the load is overdriven when the output voltage is higher than the required value. In this situation, the duty cycle of the PWM signals V_{HG} and V_{LG} should be reduced.

Note that the input current I_{pc} in Figure 5 is a pulse current as shown in the graph of Figure 2. The power factor of the conventional switching power supply is significantly decreased (typically by about 50%) due to the distorted input current, causing the total harmonics distortion (hereinafter referred to as THD) to exceed 100% after the rectification performed by the AC/DC rectifier 1 shown in Figure 1. As a result, the total harmonics is seriously distorted, the quality is poor, and worse yet, precious energy is wasted.

Thus, many countries have promulgated a number of harmonic current rules (e.g., EN-6100-3-2) which specify the current wave shape for power supplies that must be obeyed by manufacturers in order to improve the efficiency and quality of the power source being supplied.

As such, various designs of power factor correction circuits have been proposed by researchers in order to improve the power factor of the conventional switching power supply. Two examples of typical prior art are described in the following:

1. Inductor-Type Power Factor Correction Circuit

As shown in Figure 3, the prior art discloses a design in which a low

frequency large winding L_1 is in series between a bridge rectifier BD_1 and an electrolytic capacitor C_1. The winding L_1 and the capacitor C_1 form a low pass filter to rectify the input current of a DC/DC converter 2. Such a design is similar in function to the ballast for correcting the power factor of a fluorescent lamp. However, the winding L_1 is relatively large, has only a limited power factor improvement, and creates an abnormally high temperature during operation.

2. Active-Type Power Factor Correction Circuit

As shown in Figure 4, the prior art discloses a design in which the AC/DC rectifier is redesigned to form a two-stage circuit with the DC/DC converter 2. Further, a complex control circuit 11 and a large switch element Q_1 are added therein to improve the power factor. However, it is relatively complex in circuit design and is expensive to manufacture.

Many power factor correction circuits have been developed based on the basic concepts involved in the two examples of prior art mentioned above, all with similar drawbacks.

Summary of the Invention

In accordance with the foregoing description, there are many drawbacks to the conventional power factor correction circuit. For example, the circuit structure depicted in Figure 3 is relatively large, while the circuit structure depicted in Figure 4 is relatively complex in circuit design and is expensive to manufacture.

Therefore, the main purpose of the present invention is to provide a power factor correction circuit with a high power factor.

Another purpose of the present invention is to provide a power factor correction circuit that solves the problems existing in the prior art.

A further purpose of the present invention is to provide a switching power supply structure that is small and economical to manufacture.

It is an objective of the present invention to provide a power factor correction circuit comprising a series connection of a first winding, a diode, an inductor and a first capacitor. The inductor is used to filter the voltage from the diode. The first winding can be one additional winding of the transformer. A primary winding is connected at a point between the inductor and the first capacitor. The polarity of the first winding is opposite to that of the primary winding. A second capacitor is connected to the primary winding to control the primary winding and build a voltage across the first capacitor. This voltage is transferred to the first winding through the transformer. The transferred voltage can boost the first capacitor voltage to improve the power factor.

Brief Description of the Drawings

The foregoing aspects and many of the attendant advantages of this invention will become more readily appreciated and better understood by referencing the following detailed description, when taken in conjunction with the accompanying drawings, wherein:

Figure 1 is a circuit diagram of a prior art off-line switching power

supply;

Figure 2 is a graph showing the wave pattern of the input voltage versus the input current of FIG. 1;

Figure 3 is a circuit diagram of an inductor-type power factor correction circuit according to the prior art;

Figure 4 is a circuit diagram of an active-type power factor correction circuit according to the prior art;

Figure 5 is a circuit diagram of a switching power supply designed with half-bridge topology according to the prior art;

Figure 6 is a timing diagram of the PWM signals, V_{HG} and V_{LG}, which are usually used to drive the switching devices in conventional bridge converters;

Figure 7 illustrates an active-type power factor correction circuit used in a flyback–type switching power supply according to the preferred embodiment of the present invention;

Figure 8 illustrates a simplified circuit diagram of the primary-side circuit without showing the auxiliary power supply;

Figure 9 illustrates an enlarged diagram of the voltage V_{P1} polarity of the winding P_1;

Figure 10 illustrates another enlarged diagram of the voltage V_{P1} polarity of the winding P_1; and

Figure 11 is a waveform diagram showing the relationship among the critical voltages, V_{C1} and V_{S1}, and the input current I_2 of the present invention.

Detailed Description of the Preferred Embodiment

Without limiting the spirit and scope of the present invention, the circuit structure proposed in the present invention is illustrated with one preferred embodiment. One with ordinally skill in the art, upon acknowledging the embodiment, can apply the power factor correction circuit structure of the present invention to various switching power supplies. The circuit structure of the present invention allows a high power factor and a relatively small volume. Furthermore, the present invention does not require an additional inductor nor an additional power factor correction clock. Therefore, the size of the circuit structure is reduced and the manufacturing cost is also reduced. The application of the present invention is not limited by the preferred embodiment described in the following.

The present invention provides a circuit structure including a power factor correction circuit and a switching power supply.

Figure 7 illustrates an active-type power factor correction circuit used in a flyback–type switching power supply according to the preferred embodiment of the present invention. It is noticed that the power factor correction circuit of the present invention also can be used in another type of converter, such as the forward-type, push-pull-type, half-bridge-type–, full-bridge-type or resistor-capacitor-control type.

In Figure 7, the transformer T_1 has a primary winding P_1, a secondary winding S and an additional winding P_1 of the power factor correction circuit 710. The power factor correction circuit 710 is used to improve a power factor of a switching power supply. The voltage V_{S1} is the AC input power. The

current I_{S1} is the current generated by the AC input power. The bridge rectifier BD_1 rectifies the AC power to DC power. The capacitor C_3 is used to filter the noise from the input end. The high-frequency pulse signal control circuit 712 outputs the PWM signal to control the switching transistor 714. The feedback system 716 receives the output signal V_O that is transferred from the output end and sends out a feedback signal to the high-frequency pulse signal control circuit 712. Then, the high-frequency pulse signal control circuit 712 modulates the duty cycle of the PWM signal that is sent to the switching transistor 714 in order to steady the output signal V_O.

In accordance with the present invention, the power factor correction circuit 710 is composed of a winding P_1, a diode D_1, an inductor L and a capacitor C_1 arranged in series. The inductor L is used to filter the input voltage from the diode D_1. The winding P_1 and the primary winding P_2 are arranged in the same core such that they have opposite polarities. Therefore, the primary winding P_2 is able to transfer a voltage in the winding P_1 that is inverse to that of the primary winding P_2.

Referring to Figure 8, a simplified circuit diagram of the primary-side circuit is shown without the auxiliary power supply. The dotted line depicted in Figure 8 represents the direction of current I_1 flow. When the high-frequency pulse signal control circuit turns on the switching transistor 714, the capacitor C_1, with an original voltage V_{C1}, is discharged by the current I_1 through the winding P_2. The energy is stored in the winding P_2 to build a voltage V_{P2} in the winding P_2. At switching transistor 714 off, the power is transferred from the core to secondary winding S and the winding P_1. Then, the power is supplied to the load (not shown) and the winding P_1 while building a voltage V_{P1} in the

winding P_1 that is inverse to V_{P2}. The voltage V_{P1} is related to the duty time of the switching transistor 714 when turned on and the ratings of the primary windings P_2 and P_1. The voltage V_{P1} across the winding P_1 is shown as follows:

$$V_{P1} = V_{C1} \times \frac{P_1}{P_2} \times \textit{switching transistor (turned on duty)}$$

$$\textit{wherein } \frac{P_1}{P_2} \textit{ is the turns ratios of the winding } P_1 \textit{ to the primary winding } P_2$$

Figure 9 illustrates an enlarged diagram of the voltage V_{P1} polarity of the winding P_1. The voltage V_{S1} is the AC input power. Therefore, the input voltage V_{D1} applied to the diode D_1 is shown as follows:

$$V_{D1} = V_{S1} + V_{P1}$$

When the input voltage V_{D1} is larger than the voltage V_{C1} of the capacitor, the diode D_1 is forward-biased. The diode D_1 is turned on and a current I_2 is generated. According to the preferred embodiment, the winding P_1 and the winding P_2 are designed to make the input voltage V_{D1} always larger than the voltage V_{C1} when the switching transistor is turned on. Referring to Figure 8 again, the solid line indicates the direction of current I_2 flow. The current I_2 charges the capacitor C_1.

When the high-frequency pulse signal control circuit turns off the switching transistor 714, the power is transferred from the core to the secondary winding S_1. Then, the power is supplied to the load (not shown) and the capacitor C_2 from the secondary winding S_1. At this time, the polarity of the winding P_1 is reversed. Figure 10 illustrates an enlarged diagram of the voltage V_{P1} polarity of the winding P_1. The voltage V_{S1} is the AC input power.

Therefore, the input voltage V_{D1} applied to the diode D_1 is shown as follows:

$$V_{D1} = V_{S1} - V_{P1}$$

According to the preferred embodiment, the winding P_1 and the winding P_2 are designed to make the input voltage V_{D1} always less than the voltage V_{C1} when the switching transistor is turned off. Therefore, the diode D_1 is reverse-biased and no current flows through the diode D_1 to charge the capacitor C_1.

On the other hand, referring to Figure 7 again, the output voltage V_O is transferred to a feedback system. The feedback system feeds a signal back to the high-frequency pulse signal control circuit 712 to modify the duty cycle of the PWM signal. For example, if the power supplied to the load is insufficient when the output voltage is lower than the specific value, the feedback signal lengthens the duty cycle of the PWM signal to increase the time spent in turning on the switching transistor 714. In effect, power is transferred from the primary winding to the secondary winding of the transformer T_1 for a longer period of time; that is, the power supplied to the secondary winding is increased. The output voltage V_O consequently increases to attain the required value. However, the power supplied to the load is overdriven when the output voltage is higher than the required value. In this situation, the duty cycle of the PWM signal should be reduced.

Figure 11 is a waveform diagram showing the relationship among the critical voltages, V_{C1} and V_{S1}, and the input current I_2 of the present invention. Referring to Figure 8 and Figure 11, the voltage V_{S1} is the AC input power. The voltage V_{C1} is the voltage across the capacitor C_1. The current I_2 is the current to charge the capacitor C_1. The input voltage V_{D1} is the voltage applied

to the diode D_1.

Therefore, when the input voltage V_{D1} is larger than the voltage V_{C1} of the capacitor, the diode D_1 is forward-biased. The diode D_1 is turned on and a current I_2 is generated. The current I_2 charges the capacitor C_1, which can improve the power factor correction. When the input voltage V_{D1} is less than the voltage V_{C1} of the capacitor, the diode D_1 is reverse-biased. The diode D_1 is turned off and no current I_2 is generated. When the ratio of the number of the turns of the winding P_1 to the winding P_2 approaches 1, the power factor also approaches 1.

Accordingly, the present invention provides a power factor correction circuit comprising a series connection of a first winding, a diode, an inductor and a first capacitor. The first winding is one additional winding of the transformer. The polarity of the first winding is opposite to that of the primary winding. A second capacitor is connected to the primary winding to control the primary winding and build a voltage across the first capacitor. This voltage is transferred to the first winding through the transformer. The transferred voltage can boost the first capacitor voltage to improve the power factor.

As is understood by a person skilled in the art, the foregoing descriptions of the preferred embodiment of the present invention are an illustration of the present invention rather than a limitation thereof. Various modifications and similar arrangements are included within the spirit and scope of the appended claims. The scope of the claims should be accorded to the broadest interpretation so as to encompass all such modifications and similar structures. While a preferred embodiment of the invention has been illustrated and described, it will be appreciated that various changes can be

made therein without departing from the spirit and scope of the invention.